

# Performance Analysis of TCSC Controller with a power system

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**Abstract— In this paper the design of robust fuzzy logic Thyristor Controlled Series compensator (TCSC) for stability of a single machine infinite bus (SMIB). The performance of the system with robust fuzzy logic based Thyristor Controlled Series compensator is compared with the system having conventional Thyristor Controlled Series compensator. The results show that the system with robust fuzzy logic controller is capable of stabilizing the system faster than the conventional controllers.**

**Keywords—** Power system stability, robust control, fuzzy logic, SMIB power system, Thyristor Controlled Series Compensator.

## I. INTRODUCTION

Modern power systems are characterized by extensive system interconnections and increasing dependence on control for optimal utilization of existing resources. The supply of reliable and economic electrical energy is a major determinant of industrial progress and consequent rise in the standard of living. The increasing demand for electric power coupled with resource and environmental constraints pose several challenges to system planners. The generation may have to be sited at location far away from load centers [1]. However, con-impetus to seek technological solutions for exploiting the high thermal loading limits of EHV lines. With deregulation of power supply utilities, there is a tendency to view the power networks as highways for transmitting electric power from wherever it is available to place where required, depending on the pricing that varies with time of the day.

Stability of power systems continue to be of major concern in system operation. This arises from the facts that in steady state, the average electrical speed of all the generators must remain the same anywhere in the system. This termed as the

synchronous operation of a system. Any disturbance small or large can affect the synchronous operation.

For example, there can be a sudden increase in the load or loss of generation. Another type of disturbance is the switching out of a transmission line, which may occur due to overloading or a fault. Due to this the stability of the system is affected. Then the system can settle to a new original steady state after the transients disappear.

By means of flexible and rapid control over the AC transmission parameters and network topology, Flexible Ac Transmission System (FACTS) technology can facilitate the power control, enhance the power control, enhance the power transfer capability, decrease the line losses and generation costs, and improve the stability and security of the power system [2]. For the analysis of small signal stability accurate representation of system dynamics along with tuned FACTS controller is essential.

In paper [1] the stability analysis of SMIB power system with TCSC controller is discussed also in paper [2] the robust controller using loop shaping design of TCSC is made in SMIB system. In paper [3] the coordination control of excitation system is discussed. In paper [4] in design of SMIB system using multi objective optimization technique is used. In paper [5] and [6] the robust control implementation on TCSC controller is discussed. in paper [7] and [8] the of fuzzy login in design of TCSC controller is designed. In paper [9] the author discuss the coordination of excitation system is discussed.

Conventional TCSC is used in existing power system stabilizers is contribution in enhancing power system dynamic stability. The parameters of TCSC are determined based on linearized model of the power system around a nominal operating point where they can provide good performance. Since power systems are highly nonlinear systems, with configurations and parameters that change with time, the TCSC design based on the linearized model of the power system cannot guarantee its performance in a practical operating environment. To improve the performance of conventional TCSC, numerous techniques have been proposed for their design, such us using genetic algorithm, neural networks, fuzzy logic and many other nonlinear control techniques.

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## II. DESIGN OF CONVENTIONAL TCSC CONTROLLER

Thyristor Controlled Series Compensation is used in power systems to dynamically control the reactance of a transmission line in order to provide sufficient load compensation. The benefits of TCSC are seen in its ability to control the amount of compensation of a transmission line, and in its ability to operate in different modes. These traits are very desirable since loads are constantly changing and cannot always be predicted [3].

The circuit diagram of a TCSC is shown in Figure 1. It consists of three components: capacitor banks C, bypass inductor L and bidirectional thyristors SCR<sub>1</sub> SCR<sub>2</sub>. In Figure 1,  $i_C$  and  $i_L$  are the instantaneous values of the currents in the capacitor banks and inductor, respectively;  $i_s$  is the instantaneous current of the controlled transmission line;  $v$  is the instantaneous voltage across the TCSC.

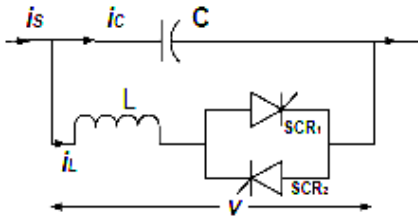


Figure 1: Variable inductor connected in shunt with a fixed capacitor

The control of the TCSC is achieved by the firing angle signal  $\alpha$ , which changes the fundamental frequency reactance of the compensator. There exists a steady-state relationship between the firing angle  $\alpha$  and the reactance  $X_{TCSC}(\alpha)$ . This relationship can be described in the following equation.

$$X_{TCSC}(\alpha) = X_C - \frac{X_C^2}{X_C - X_P} \frac{\sigma + \sin \sigma}{\Pi} + \frac{4X_C^2}{X_C - X_P} \frac{\cos^2(\sigma/2)(k \tan(k\sigma/2) - \tan(\sigma/2))}{(k^2 - 1)\Pi} \quad (1)$$

Where,

$X_C$  = Nominal reactance of the fixed capacitor C

$X_P$  = Inductive reactance of inductor L connected parallel with C

$\sigma = 2(\pi - \alpha)$  = Conduction angle of TCSC controller

$k$  = Compensation ratio.

The equation (1) is the fundamental frequency reactance offered by TCSC,  $X_{TCSC}(\alpha)$ , is a unique-valued function; the TCSC is modeled here as a variable capacitive reactance within the operating region defined by the limits imposed by  $\alpha$ . Thus  $X_{TCSC \min} \leq X_{TCSC}(\alpha) \leq X_{TCSC \max}$ , with  $X_{TCSC \min} = X_{TCSC}(180^\circ)$  and  $X_{TCSC \max} = X_{TCSC}(\alpha_{\min})$ . In this paper, the Controller is assumed to operate only in the capacitive region, i.e.,  $\alpha_{\min} > \alpha_r$  where  $\alpha_r$  corresponds to the resonant point, as the inductive

region associated with  $90^\circ < \alpha < \alpha_r$  induces high harmonics that cannot be properly modeled in stability studies [4].

A: *Robust H $\infty$  Loop shaping TCSC controller:*

The robust TCSC are designed based on H $\infty$  loop shaping control [8]. The design procedure is divided into 3 steps as follows.

**Step 1: Loop shaping**

As shown in Figure 2, a pre compensator  $W_1$  and a post compensator  $W_2$  are employed to form the augmented plant  $G_s = W_2 G W_1$ , which is enclosed by a solid line.

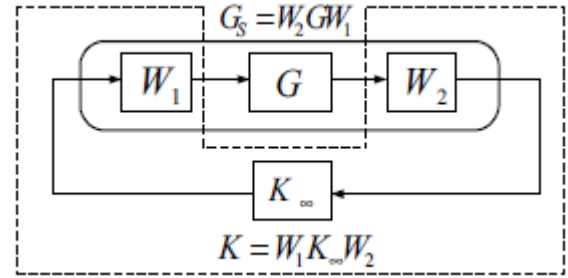


Figure 2: Shaped plants G and designed robust controller K.

The designed robust stabilizer  $K = W_1 K_\infty W_2$  is enclosed by a dotted line where  $K_\infty$  is the H $\infty$  controller. The weighting function can be selected as  $W_1 = W$  and  $W_2 = 1$ .

**Step 2: Formulation of H $\infty$  robust stabilization problem**

A shaped plant  $G_s$  is expressed in form of normalized left co-prime factor  $G_s = M_s^{-1} N_s$ , when the perturbed plant  $G_\Delta$  is defined as,

$$G_\Delta = \{(M_s + \Delta M_s)^{-1} (N_s + \Delta N_s) : \|[\Delta N_s \ \Delta M_s]\|_\infty \leq 1/\gamma\} \quad (2)$$

Where,  $\Delta M_s$  and  $\Delta N_s$  are stable unknown transfer functions which represent uncertainties in the nominal plant model G. Based on this definition, the H $\infty$  robust stabilization problem can be established by  $G_\Delta$  and K as depicted in Figure 4. The objective of robust control design is to stabilize not only the nominal plan G but also the family of perturbed plant  $G_\Delta$ . In equ (2)  $1/\gamma$  is defined as the robust stability margin.

The maximum stability margin in the face of system uncertainties is given by the lowest achievable value of  $\gamma$ , i.e.  $\gamma_{\min}$ . Hence,  $\gamma_{\min}$  implies the largest size of system uncertainties that can exist without destabilizing the closed loop system in Fig. 4. The value of  $\gamma_{\min}$  can be easily calculated from

$$\gamma_{\min} = \sqrt{1 + \lambda_{\max}(XZ)} \quad (3)$$

Where  $\gamma_{\max}(XZ)$  denotes the maximum Eigen value of  $XZ$ . For minimal state-space realization  $(A, B, C, D)$  of  $s G_s$ , the values of  $X$  and  $Z$  are unique positive solutions to the generalized control algebraic Riccati equation

$$(A - BS^{-1}D^T C)^T X + X(A - BS^{-1}D^T C) - XBS^{-1}B^T X + C^T R^{-1}C = 0 \quad (4)$$

And the generalized filtering algebraic Riccati equation

$$(A - BS^{-1}D^T C)Z + Z(A - BS^{-1}D^T C)^T - ZC^T R^{-1}CZ + BS^{-1}B^T = 0 \quad (5)$$

Where  $R = I + DD^T$  and  $S = I + D^T D$ . Note that no iteration on  $\gamma$  is needed to solve for  $\gamma_{\min}$ . To ensure the robust stability of the nominal plant, the weighting function is selected so that  $\gamma_{\min} \leq 4.0$  [8]. If  $\gamma_{\min}$  is not satisfied, then adjust the weighting function.

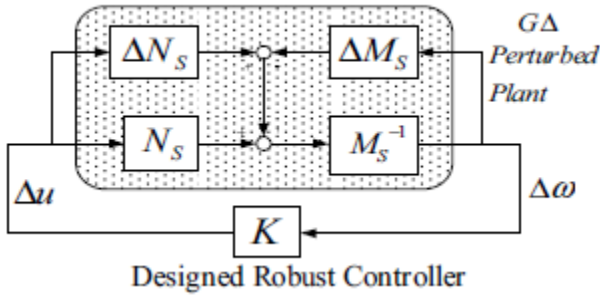


Figure 3:  $H_{\infty}$  robust TCSC controller

### Step 3 Determination of Robust controller:

The  $K_{\infty}$  controller in Figure 3 can be determined by,

$$K_{\infty} = \begin{bmatrix} A + BF + \gamma^2 (L^T)^{-1} ZC^T (C + DF) & \gamma^2 (L^T)^{-1} ZC^T \\ B^T X & -D^T \end{bmatrix} \quad (6)$$

Where,  $F = -S(D^T C + B^T X)$  and  $L = (1 - \gamma^2)I + XZ$ .

Next, find robust controller  $K(s) = W_1 K_{\infty} W_2$  that satisfies the necessary condition

$$\left\| \begin{bmatrix} I \\ K_{\infty} \end{bmatrix} (I - G_s K_{\infty})^{-1} [I \ G_s] \right\|_{\infty} \leq \gamma \quad (7)$$

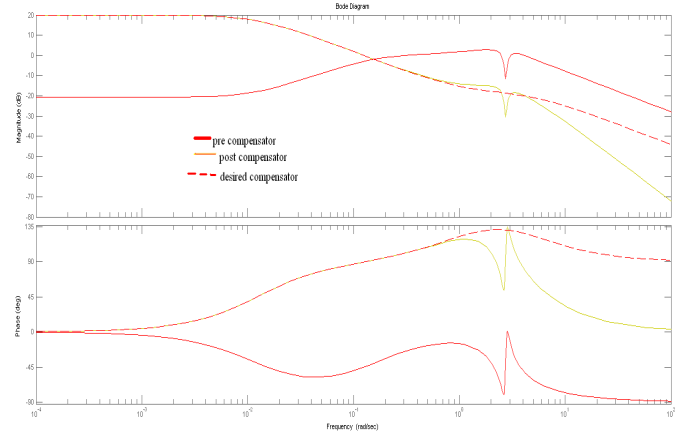


Figure 4: Bode plot of loop shaping TCSC controller with  $W_1$  and  $W_2$  matrix

Figure 4 depict the bode plot of loop shaping TCSC controller, here the magnitude plot of the robust TCSC controller is between the pre-compensator  $W_1$  and post compensator  $W_2$  this signifies the stabilizing effects of the controller.

## III. DESIGN OF SMIB POWER SYSTEM

### A: System Modeling:

The single-machine infinite-bus (SMIB) power system installed with a TCSC, shown in Figure 6, is considered in this study. In the Figure,  $X_T$  and  $X_L$  represent the reactance of the transformer and the transmission line respectively;  $V_T$  and  $V_B$  are the generator terminal and infinite bus voltage respectively.

In the design of electromechanical mode damping stabilizer, a linearized incremental model around an operating point is usually employed. The figure 6 shows the Phillips-Heffron model of the power system with FACTS devices is obtained by linearizing nonlinear equations of the power system around an operating condition [11].

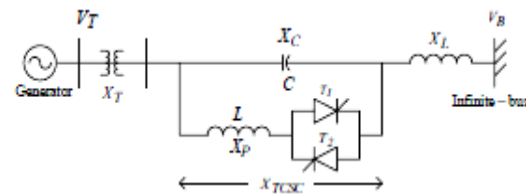


Figure 5: Single Machine Infinite Bus power system with TCSC

### B: Non linear modeling:

In the non linear modeling of SMIB system we use the synchronous generator which is represented by model 1.0, i.e. with field circuit and one equivalent damper winding on q axis. The machine equations are described by,

1: stator winding equation:

$$V_q = -r_s i'_q - x_d i'_d + E_q \quad (8)$$

$$V_d = -r_s i'_d + x_q i'_q + E_d \quad (9)$$

Where,

$r_s$  - The stator winding resistance  
 $x_d'$  - The d-axis transient resistance  
 $x_q'$  - The q-axis transient resistance  
 $E_q'$  - The q-axis transient voltage  
 $E_d'$  - The d-axis transient voltage

2: Rotor winding equation:

$$T_{do}' \frac{dE_q'}{dt} + E_q' = E_f - (x_d - x_d') i_d \quad (10)$$

$$T_{qo}' \frac{dE_d'}{dt} + E_d' = (x_q - x_q') i_d \quad (11)$$

Where,

$T_{do}'$  - is the d-axis open circuit transient time constant  
 $T_{qo}'$  - is the q-axis open circuit transient time constant  
 $E_f$  - is the field voltage

C: Linearized modeling:

The Linearized model of SMIB system with TCSC controller is represented by Phillips-Heffron linear model. As shown in Figure 7.

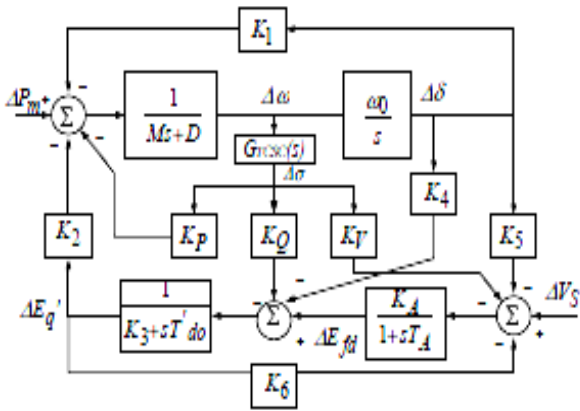


Figure 6: Phillips-Heffron model of SMIB with TCSC

The mathematical model of the Linearized SMIB system is as follows;

$$\Delta \delta = \omega_b \Delta \omega \quad (12)$$

$$\Delta \omega = [-K_1 - \Delta \delta - K_2 \Delta E_q' - K_p \Delta \sigma - D \Delta \omega] / M \quad (13)$$

$$\Delta E_q' = \frac{[-K_3 \Delta E_q' - K_4 \Delta \delta - K_q \Delta \sigma + \Delta E_{fd}']}{T_{do}'} \quad (14)$$

$$\Delta E_{fd}' = \frac{[-K_A (K_5 \Delta \sigma + K_6 \Delta E_q' + K_v \Delta \sigma) - \Delta E_{fd}']}{T_A'} \quad (15)$$

Where,

$$K_1 = \frac{\partial P_6}{\partial \delta} \quad K_2 = \frac{\partial P_6}{\partial E_q'} \quad K_3 = \frac{\partial E_q'}{\partial E_q'}$$

$$K_4 = \frac{\partial E_q'}{\partial \delta} \quad K_5 = \frac{\partial V_T}{\partial \delta} \quad K_6 = \frac{\partial V_T}{\partial E_q'}$$

#### IV. DESIGN OF ROBUST FUZZY LOGIC TCSC CONTROLLER

The Robust fuzzy logic controller design consists of the following steps:

- Identification of input and output variables
- Construction of control rules
- Establishing fuzzification method and fuzzy membership functions
- Selection of the compositional rule of inference
- Defuzzification method, so transformation of the fuzzy control statement into specific actions.

The variables for FLTCS are speed deviation, acceleration and voltage. The speed deviation and acceleration are inputs variables and voltage is the output variables. In practice, only shaft speed is readily available.

The acceleration signal can be derived from speed signals measured at two successive sampling using

$$\Delta \omega(k) = \frac{\Delta \omega(k) - \Delta \omega(k-1)}{\Delta T} \quad (16)$$

Each of the input and output variables are seven linguistic fuzzy: NB (Negative Big), NM (Negative Medium), NS (Negative Small), Ze (Zero), PS (Positive Small), PM (Positive Medium), PB (Positive Big). The triangular membership functions are used to define the degree of membership. The variables are normalized by multiplying with gains so that their value lies between -1 and 1. The membership function for inputs and outputs are shown in figure 8.

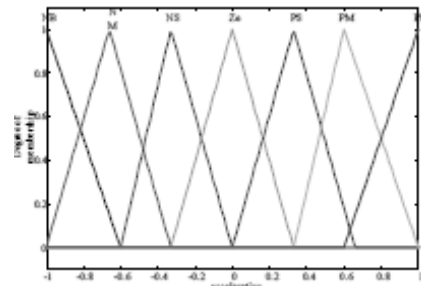


Figure 7: Input1 membership function

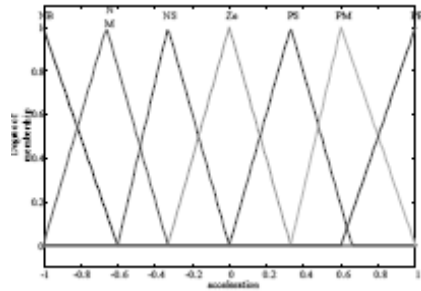


Figure 8: Input 2 membership function

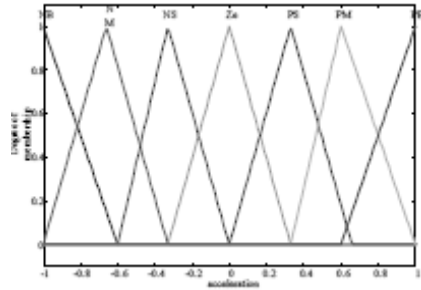


Figure 9: Output membership function

The two inputs are speed and acceleration, which results in 49 rules for each machine.

Example, IF  $e(t)$  is PB and derivative of  $e(t)$  is zero, THEN the  $K_p$  is PB.

All the 49 rules are explained in table 1. The stabilizers output is obtained by applying a particular rule expressed in the form of membership functions. Finally the output membership function of the rule is calculated. The surface of control is shown in figure 9.

TABLE I  
Rule base of fuzzy logic controller

INPUT1	INPUT 2						
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NM	NS
NM	NB	NM	NM	NM	NS	NS	ZE
NS	NM	NM	NS	NS	ZE	ZE	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NM	ZE	ZE	PS	PS	PM	PM
PM	NS	PS	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PB	PB	PB	PB

## V. SIMULATION RESULTS

The Simulink model for simulations of SMIB with fuzzy robust TCSC controller is shown in figure 10. The characteristics showing the variation in speed deviation, accelerating power and terminal voltage are presented in figure 11. It observes that the oscillations are more pronounced when

a system is perturbed with constant field voltage after which it becomes stable. The excitation system parameters are  $K_A = 200$  and  $T_A = 0.02$ . The time response of the angular speed, angular position for a 5% step change in mechanical input is presented in figure 12.

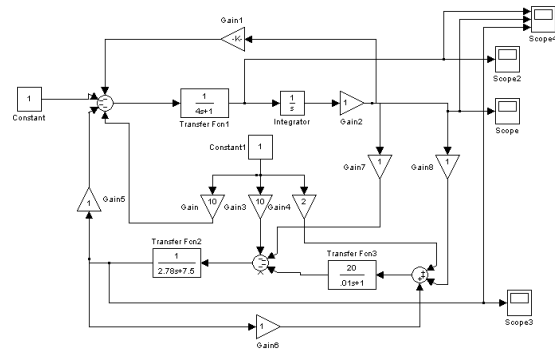


Figure 10: simulation of SMIB with robust fuzzy TCSC controller

The model used in Simulink to analyze the effect of robust fuzzy logic TCSC controller in damping small signal oscillations when implemented on SMIB system is shown in figure 10. To compare the performance of conventional TCSC and robust fuzzy logic based TCSC, the step response are shown in figures 11, 12 and 13. From figures above it can be perceived that with the application of fuzzy logic the rise time and settling time of the system decreases. The system reaches its steady state value much earlier with robust fuzzy logic TCSC compared to conventional TCSC.

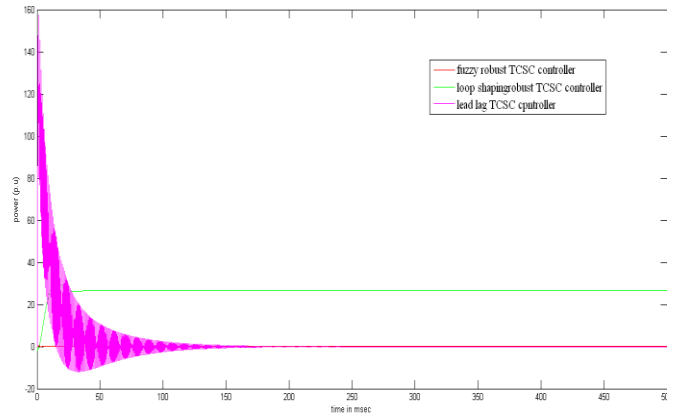


Figure 11: speed deviation of SMIB with Lead Lag TCSC and Robust fuzzy logic TCSC controller.

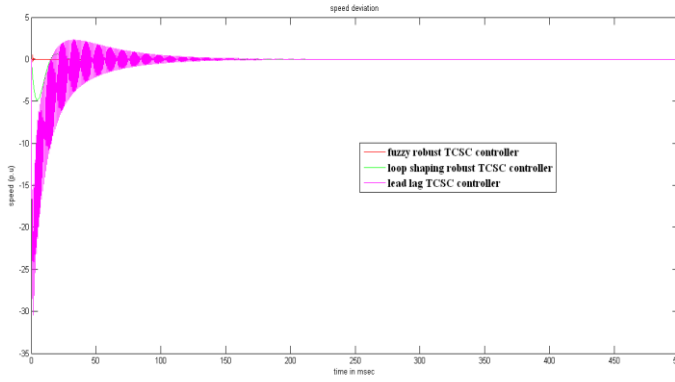


Figure 12: terminal voltage of SMIB with Lead Lag TCSC and Robust Fuzzy logic TCSC controller.

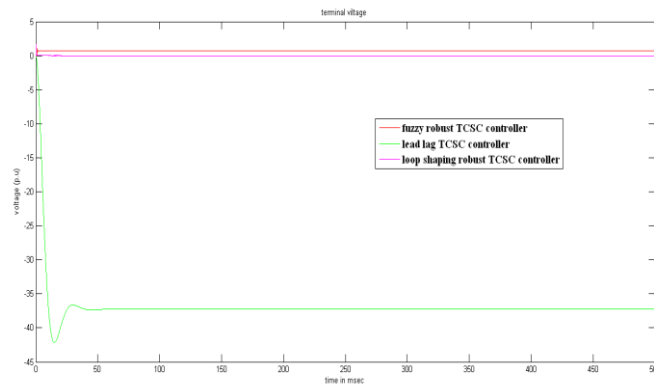


Figure 13: accelerating power of SMIB system with Lead Lag controller with Robust Fuzzy logic TCSC controller.

TABLE 2:

Comparison of lead-lag, robust  $H_{\infty}$  tsc controller and robust fuzzy logic tsc controller based on settling time ( $T_s$ ) msec

Parameter of SMIB power system	Settle time $T_s$ in msec		
	Lead lag TCSC	Robust $H_{\infty}$ TCSC	Robust fuzzy TCSC
Speed deviation	24	4	3.8
voltage	38	4.8	4.2
Accelerating power	30	3.2	3.3

From the table 2 it is clear that the robust fuzzy TCSC controller makes the system stable faster than the conventional Lead Lag TCSC controller

## VI. CONCLUSION

In this work three structure of TCSC controller namely, conventional Lead Lag controller, robust  $H_{\infty}$  loop shaping TCSC controller, robust fuzzy logic controller is designed and modelled in Single Machine Infinite Bus (SMIB)

power system in same operating condition. Modeling and simulation are obtained using simulation in Matlab 7.0. With three structure of TCSC controller in SMIB system under same operating conditions. The performance of SMIB system is analysed with various SMIB parameters like terminal voltage, accelerating power, speed deviations are obtained.

From the simulation output the settling time ( $T_s$ ) of various parameters is found. It is observed that the robust fuzzy logic TCSC controller makes SMIB power system damp out the oscillation faster and makes the system stable faster than the other controllers

## VII. APPENDIX

Generator:  $M = 9.26$  s.,  $D = 0$ ,  $X_d = 0.973$ ,  $X_q = 0.5$ ,  $X'_d = 0.19$ ,  $T'_{do} = 7.76$ ,  $f = 60$ ,  $V_T = 1.05$ ,  $X_{TL} + X_T = 0.997$ .

Exciter:  $K_A = 50$ ,  $T_A = 0.05$  s,  $T_A = 0.05$  s.

TCSC Controller:  $X_{TCSC} = 0.2169$ .  $k=2$ ,  $T_1 = T_3$ ,  $T_2 = T_4$ ,  $T_{ws}=10$  s.

System matrix:

$$A = \begin{bmatrix} 0 & 377 & 0 & 0 \\ -0.2918 & 0 & 0 & -0.1253 \\ 7.21 & 0 & -33.33 & -6.185 \\ 0.421 & 0 & 1.587 & -0.373 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 \\ 0.312 & 0 \\ -10.53 & 133.33 \\ 0.253 & 0 \end{bmatrix} \quad \text{Further,}$$

$$\begin{bmatrix} \Delta V_m \\ \Delta P_m \end{bmatrix} = \begin{bmatrix} -0.031 & 0.1128 & 0.2158 \\ 0.8965 & -0.2166 & 0.6523 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta e_q \\ \Delta B \end{bmatrix}$$

## REFERENCES

- [1] Dr.S. Latha , Dr. Mary raja Slochanal and J.Pandia Rajan., "Stability analysis of Single Machine Infinite Bus power system with TCSC controller", CiiT International Journal of Data mining and knowledge engineering, Vol. 2, No. 11, November 2010, pp. 354–359.
- [2] Dr.S. Latha, K. Dhanalakshmi, J.Pandia Rajan., "Design of Robust  $H_{\infty}$  loop shaping TCSC controller over conventional TCSC controller for SMIB system", Proceedings of 1st National Conference on Emerging Trends in Engineering and Technology, Anna university of Technology, Madurai , April 2011, pp. 234–241.
- [3] Mahran AR, Hogg BW, Al-Sayed ML. "Coordinated control of synchronous generator excitation and static var compensator," IEEE Trans Energy Conversion, Vol. 7, 2010
- [4] Sidhartha Panda, A.K.Baliarsingh, "R.K.Sahu Multi-Objective Optimization Technique for TCSC-Based Supplementary Damping Controller Design", IEEE Trans. Power Delivery, Vol. 12, No. 2, pp. 941- 946, 2009.

- [5] Cuk Supriyadi A. N., I. Ngamroo, S. Kaitwanidvilai, A. Kunakorn, T. Hashiguchi, and T. Goda, "Loop Shaping-based Robust Control Design of PSS and TCSC for Dynamic Stability Enhancement", Proceedings of ECTI-CON 2008
- [6] B. H. Li, Q. H. Wu, D. R. Turner, P. Y. Wang, X. X. Zhou, "Modeling of TCSC Dynamics for Control and Analysis of Power System Stability", Int. J. of Electrical Power & Energy Systems, Vol. 22, No. 1, pp. 43–49, 2008.
- [7] S. Panda, N. P. Padhy, R. N. Patel, "Modeling, simulation and optimal tuning of TCSC controller", International Journal of Simulation Modeling, vol. 6, no. 1, pp. 7-48, 2007 .
- [8] Abido, M.A. "Pole placement technique for PSS and TCSC-based stabilizer design using simulated annealing," Electrical power and energy systems, Vol. 22, 2004.
- [9] Abdel-magid Y.L and Abido M.A. "Robust coordinated design of excitation and TCSC-based stabilizer using genetic algorithms," Electrical power and energy systems, Vol. 69, 2004.
- [10] L.Z. Liao, D. Li, "Adaptive differential dynamic programming for multi-objective optimal control", Automatica, vol. 38, pp. 1003-1015, 2002.
- [11] K.R.Padiyar, "power system Dynamic stability and control", BS Publication, 2<sup>nd</sup> Edition, Hyderabad, India, 2002.
- [12] N.G. Hingorani, L. Gyugyi, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems", IEEE Press, New York, 2000.

### VIII. BIOGRAPIES

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